Lesson 04 – Decision Making

The operations manager is a planner and a decision maker in environments of risk, uncertainty and certainty.

The Decision Process

1. Identify the Problem
2. Specify objectives and the criteria for choosing a solution
3. Develop alternatives
4. Analyze and compare alternatives
5. Select “best” alternative (“best” depends on whether we are considering costs or profits)
6. Implement chosen alternative
7. Monitor to ensure desired results are achieved

Causes for Poor Decisions

There are many reasons for making poor decisions:

- **Mistakes** - in the decision process (either logic in formulating the problem, solution, or calculation errors)
- **Bounded rationality** - limitations from costs, human abilities, time, technology and availability of information
- **Sub-optimization** - optimum solutions at the departmental level may not be in the best interest of the department rather than in the best interest of the whole organization
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Decision Environments

There are 3 environments under which decisions are made:

- **Certainty** - Environment in which relevant parameters have known values (e.g., Profit = $5/unit, demand = 200 units. How much profit will you make?)

- **Risk** - Environment in which probability estimates of possible future conditions are evaluated (e.g., Profit = $5/unit, demand has a probability of 50% for 100 units and 50% for 200 units. How much profit will you make?)

- **Uncertainty** - Environment in which it is impossible to assess the likelihood of various future events (e.g., Profit = $5/unit, demand is unknown. How much profit will you make?)

Decision Theory

*Decision Theory* represents a general quantitative approach to decision making which is suitable for a wide range of operations management decisions. Decisions are based on:

- **States of Nature** - A set of possible future conditions that will have a bearing on the results of the decision

- **Alternatives** - A list of considerations

- **Payoff** - A known result (could be good or bad) for each alternative under each condition (state of nature)

- **Likelihood** - Estimated probability of each future condition

- **Decision criteria** - A set of rules under which decisions are made to select the best alternative

Payoff Table

*Payoff* - A known result (could be good or bad) for each alternative under each possible future condition. Good results are usually shown as positive numbers. Bad results (costs or losses) are usually shown as negative numbers.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Facility</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Medium Facility</td>
<td>7</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Large Facility</td>
<td>-4</td>
<td>2</td>
<td>16</td>
</tr>
</tbody>
</table>
Regret (Opportunity Loss) Table

Regret (Opportunity Loss) – is based on the payoff table. The regret or lost opportunity is the difference between the best alternative payoff and each alternative payoff for each possible future demand.

<table>
<thead>
<tr>
<th>Regret</th>
<th>Possible Future Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Small Facility</td>
<td>0</td>
</tr>
<tr>
<td>Medium Facility</td>
<td>3</td>
</tr>
<tr>
<td>Large Facility</td>
<td>14</td>
</tr>
</tbody>
</table>

The best alternative payoff for low demand is 10. The regret for each alternative is 0 (10 – 10) for a small facility, 3 (10 – 7) for a medium facility, and 14 (10 - - 4) for a large facility.

Decisions Under Certainty

Decisions under certainty (known future condition) are made by selecting the alternative which has the best payoff.

<table>
<thead>
<tr>
<th>Payoff</th>
<th>Possible Future Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Small Facility</td>
<td>10</td>
</tr>
<tr>
<td>Medium Facility</td>
<td>7</td>
</tr>
<tr>
<td>Large Facility</td>
<td>-4</td>
</tr>
</tbody>
</table>

If demand is low the best alternative is a Small facility. If demand is moderate the best alternative is a Medium facility. If demand is high the best alternative is a Large facility.
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Decision Rule: For each state of nature, choose the alternative which has the highest payoff.

Note: The alternative with the highest payoff is also the alternative with the least regret.

For low demand: choose small facility
For moderate demand: choose medium facility
For high demand: choose large facility

Decisions Under Uncertainty

Decisions under uncertainty (unknown future condition) are made by selecting the alternative which has the best payoff based on one of the following decision criteria.

maximin - "best worst" payoff establishes the minimum outcome.

maximax - "best best" payoff establishes the best possible outcome.

Laplace - "best average" payoff establishes the average payoff assuming each future condition is equally likely.

minimax regret (opportunity loss) - "best worst" regret minimizes the difference between the realized payoff and the best payoff for each future condition.

Uncertainty - maximin

maximin - determine the worst payoff for each alternative across all states of nature and select the alternative with the "best worst" payoff.

<table>
<thead>
<tr>
<th>Payoff</th>
<th>Possible Future Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Small</td>
<td>10</td>
</tr>
<tr>
<td>Medium</td>
<td>7</td>
</tr>
<tr>
<td>Large</td>
<td>-4</td>
</tr>
</tbody>
</table>

The worst payoff for a small facility is 10, the worst payoff for a medium facility is 7 and the worst payoff for a large facility is -4. The maximin decision ("best worst") is 10. Therefore, we would choose the small facility alternative.
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Uncertainty - maximax
maximax - determine the best payoff for each alternative across all states of nature and select the alternative with the "best best" payoff

<table>
<thead>
<tr>
<th>Payoff</th>
<th>Possible Future Demand</th>
<th>Best Payoff</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>Small Facility</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Medium Facility</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>Large Facility</td>
<td>-4</td>
<td>2</td>
</tr>
</tbody>
</table>

The best payoff for a small facility is 10, the best payoff for a medium facility is 12 and the best payoff for a large facility is 16. The maximax decision ("best best") is 16. Therefore, we would choose the large facility alternative.

Uncertainty - Laplace
Laplace - determine the average payoff for each alternative across all states of nature and select the alternative with the "best average" payoff

<table>
<thead>
<tr>
<th>Payoff</th>
<th>Possible Future Demand</th>
<th>Average Payoff</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>Small Facility</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Medium Facility</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>Large Facility</td>
<td>-4</td>
<td>2</td>
</tr>
</tbody>
</table>

The average payoff for a small facility is 10, the average payoff for a medium facility is 10.33 and the average payoff for a large facility is 4.67. The Laplace decision ("best average") is 10.33. Therefore, we would choose the medium facility alternative.

Uncertainty – minimax regret
minimax regret (opportunity loss) - determine the worst regret for each alternative and select the alternative with the "best worst" regret

<table>
<thead>
<tr>
<th>Regret</th>
<th>Possible Future Demand</th>
<th>Worst Regret</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>Small Facility</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Medium Facility</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Large Facility</td>
<td>14</td>
<td>10</td>
</tr>
</tbody>
</table>

The worst regret for a small facility is 6, the worst regret for a medium facility is 4 and the worst regret for a large facility is 14. The minimax regret decision ("best worst") is 4. Therefore, we would choose the medium facility alternative.
Maximin Decision Rule: Calculate the maximum payoff for each alternative then choose the alternative with the maximum payoff:

Choose Small Facility

Minimax Decision Rule: Calculate the minimum payoff for each alternative then choose the alternative with the minimum payoff:

Choose Large Facility

Laplace Decision Rule: Calculate the average payoff for each alternative then choose the alternative with the maximum average payoff:

Choose Medium Facility

Minimax Regret Decision Rule: Calculate the minimum regret for each alternative then choose the alternative with the least minimum regret:

Choose Medium Facility

Decisions under risk involve evaluating outcomes where probabilities of future conditions are estimated. The decision criteria under which the decisions are made is called the Expected Monetary Value (EMV). The EMV determines the “best expected” payoff across all states of nature.

\[
EV_{\text{alternative}} = \sum_{\text{state of nature}} \text{payoff} \times \text{probability}
\]

\[
EMV = \text{best}(EV_{\text{alternative_1}}, \ldots, EV_{\text{alternative_n}})
\]
### Decisions Under Risk

\[ EV_{\text{alternative}} = \sum \text{payoff} \times \text{probability} \]

<table>
<thead>
<tr>
<th>Payoff</th>
<th>Possible Future Demand</th>
<th>Alternative</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>Expected Payoff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability</td>
<td>0.3</td>
<td>0.5</td>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small Facility</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium Facility</td>
<td>7</td>
<td>12</td>
<td>12</td>
<td>10.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large Facility</td>
<td>-4</td>
<td>2</td>
<td>16</td>
<td>3.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ EMV = \text{best} (EV_{\text{alternative}}) \]

---

**Decision Rule Payoff Table:** Calculate the expected (weighted average using the probability as weights) payoff for each alternative then choose the alternative with the maximum expected payoff: Choose Medium Facility.

**Decision Rule Regret Table:** Calculate the expected regret for each alternative then choose the alternative with the least expected regret: Choose Medium Facility. Note: Whether you use the payoff or regret table, the decision is the same!
A **Decision Tree** is a schematic representation of the options available to a decision maker. The tree shows the decision alternatives as well as the possible future conditions (states of nature) for each alternative.

Decision trees use the following conventions:
- Square nodes represent decision points
- Round nodes represent chance events
- Decision tree is read from right to left
- Decision tree is analyzed from left to right

The decision criteria under which the decisions are made is called the **Expected Monetary Value (EMV)**. The EMV determines the "best expected" payoff across all states of nature.

**Example 5:** A manager must decide on the size of a video arcade to construct. The manager has narrowed the choices to two: Large or Small. Information has been collected on payoffs, and a decision tree has been constructed. Analyze the decision tree and determine which initial alternative (build small or build large) should be chosen to maximize the **Expected Monetary Value (EMV)**.

The decision tree showing the alternatives and possible states of nature are shown on the following slide.
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**Decisions Using Decision Trees**

First, determine the "best" payoff for each state of nature.

Choose the payoff for each state of nature and decision:
- Low Demand (.4)
  - Do Nothing: $50
  - Build Small: $40
  - Build Large: $55
- High Demand (.6)
  - Do Nothing: $50
  - Reduce Prices: $50
  - Expand: $70
  - Overtime: $10

**Do Nothing**

- Low Demand: $50
- High Demand: $50

**Low Demand**

- Build Small: $40
- Build Large: $55

**High Demand**

- Do Nothing: $50
- Reduce Prices: $50
- Expand: $70
- Overtime: $10

**Decisions Using Decision Trees**

Next, determine the "expected" payoff for each alternative.

Calculate the expected payoff for each alternative:

- **Evsmall** = $40(.4) + $55(.6) = 16 + 33 = 49
- **Evlarge** = $50(.4) + $70(.6) = 20 + 42 = 62

Finally, determine the EMV "best expected" payoff.

- **Evsmall** = 49
- **Evlarge** = 62

**EMV = best(Evsmall, Evlarge) = best(49,62) = 62**

**Expected Value of Perfect Information (EVPI)**

The Expected Value of Perfect Information (EVPI) is the difference between the expected payoff under certainty (known outcomes) and the expected payoff under risk. It is a very useful decision criteria when a future condition is pending.

For example: There is discussion regarding whether or not to build a John Island Connector similar to the James Island Connector. If a bridge is built connecting John Island, property values on the John Island will increase.

An investor may want to take an option on property on John Island contingent on the bridge construction. If the bridge is eventually constructed the investor can choose whether to exercise the option.

**EVPI can help the investor determine how much greater the expected payoff due to delaying a decision to buy property on John Island is versus making a decision based on current risks. (i.e. the expected payoff above the expected monetary value)**
Expected Value of Perfect Information (EVPI)

The Expected Value of Perfect Information (EVPI) can be calculated using two different methods. Method 1 involves the “expected” payoff.

\[
EVPI = \text{Expected value of perfect information} = \text{Expected payoff under certainty} - \text{Expected payoff under risk}
\]

\[
EMV = \text{best}(EV_{\text{alternative_1}}, ..., EV_{\text{alternative_n}})
\]

\[
EV_{\text{certainty}} = \sum \text{(best payoff)} \times \text{probability}
\]

Expected Value of Perfect Information (EVPI)

The Expected Value of Perfect Information (EVPI) can be calculated using two different methods. Method 2 involves the “expected” regret.

\[
EVPI = \text{Expected value of perfect information} = \text{Expected regret under risk}
\]

\[
EMV = \text{best}(EV_{\text{alternative_1}}, ..., EV_{\text{alternative_n}})
\]

Decisions using EVPI – “expected” payoff

Example 6: Determine the Expected Value of Perfect Information (EVPI) for the payoff table shown below using “expected” payoff.

<table>
<thead>
<tr>
<th>Payoff</th>
<th>Possible Future Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.3</td>
</tr>
<tr>
<td>Alternative</td>
<td>Low</td>
</tr>
<tr>
<td>Small Facility</td>
<td>10</td>
</tr>
<tr>
<td>Medium Facility</td>
<td>7</td>
</tr>
<tr>
<td>Large Facility</td>
<td>-4</td>
</tr>
</tbody>
</table>
First, determine the **maximum** payoff for each alternative across each state of nature under certainty.

<table>
<thead>
<tr>
<th>Payoff</th>
<th>Possible Future Demand</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>Small Facility</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Medium Facility</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>Large Facility</td>
<td>-4</td>
<td>2</td>
</tr>
<tr>
<td>Best</td>
<td>10</td>
<td>12</td>
</tr>
</tbody>
</table>

Then calculate the **expected** payoff (EV under certainty) using the probability weights and the expected payoffs.

\[
EV_{\text{certainty}} = \sum (\text{best payoff}) \times \text{probability}
\]

\[
= 10(0.3) + 12(0.5) + 16(0.2) = 12.2
\]

Next, determine the **expected** payoff for each alternative across each state of nature under risk.

<table>
<thead>
<tr>
<th>Payoff</th>
<th>Possible Future Demand</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>Small Facility</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Medium Facility</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>Large Facility</td>
<td>-4</td>
<td>2</td>
</tr>
</tbody>
</table>

Then determine the **best** expected payoff (EMV).

\[
EMV = \text{best}(EV_{\text{certainty}}, EV_{\text{medium}}, EV_{\text{large}})
\]

\[
= \text{best}(10,10.5,3) = 10.5
\]

Finally, determine EVPI using **expected** payoff.

\[
EVPI = \text{Expected value of perfect information} = \text{Expected payoff under certainty} - \text{Expected payoff under risk}
\]

\[
= 12.2 - 10.5 = 1.7
\]
Example 6: Determine the Expected Value of Perfect Information (EVPI) for the payoff table shown below using “expected” regret.

Note: In the case of regret “best” means least.

<table>
<thead>
<tr>
<th>Payoff</th>
<th>Possible Future Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Probability 0.3</td>
</tr>
<tr>
<td>Alternative</td>
<td>Low</td>
</tr>
<tr>
<td>Small Facility</td>
<td>10</td>
</tr>
<tr>
<td>Medium Facility</td>
<td>7</td>
</tr>
<tr>
<td>Large Facility</td>
<td>-4</td>
</tr>
</tbody>
</table>

First, determine the regret table.

<table>
<thead>
<tr>
<th>Regret</th>
<th>Possible Future Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Probability 0.3</td>
</tr>
<tr>
<td>Alternative</td>
<td>Low</td>
</tr>
<tr>
<td>Small Facility</td>
<td>0</td>
</tr>
<tr>
<td>Medium Facility</td>
<td>3</td>
</tr>
<tr>
<td>Large Facility</td>
<td>14</td>
</tr>
</tbody>
</table>

Next, determine the “expected” regret for each alternative across each state of nature under risk.

<table>
<thead>
<tr>
<th>Regret</th>
<th>Possible Future Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Probability 0.3</td>
</tr>
<tr>
<td>Alternative</td>
<td>Low</td>
</tr>
<tr>
<td>Small Facility</td>
<td>0</td>
</tr>
<tr>
<td>Medium Facility</td>
<td>3</td>
</tr>
<tr>
<td>Large Facility</td>
<td>14</td>
</tr>
</tbody>
</table>

Then, determine the EVPI = Expected Monetary Value (“least” regret).

\[
EMV = \text{best}(EV_{\text{Small}}, EV_{\text{Medium}}, EV_{\text{Large}}) = \text{best}(2.2, 1.7, 9.2) = 1.7
\]
Sensitivity Analysis

Sensitivity Analysis is a method that is used to determine the probability range of a future condition (state of nature) over which an alternative is best. It can also be used to determine the probability at which the alternatives are the same.

Sensitivity analysis can be used when many states of nature and many alternatives are involved. For purposes of this lecture, we will only discuss situations where there are two states of nature providing an excellent visual understanding of the concept.

The methodology of sensitivity analysis relies on the knowledge of equations, the ability to plot equations and the ability to solve simultaneous equations.
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Sensitivity Analysis Example

Example 8: A manager is trying to determine which alternative warehouse site will be best. His/her decision is based on whether or not a new bridge will be built. The payoff table for the analysis is shown below. Using graphical sensitivity analysis determine the probability for “no new bridge” where each alternative is optimal.

<table>
<thead>
<tr>
<th>Payoff / (Loss) Table</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S1</td>
<td>S2</td>
<td>S1</td>
</tr>
<tr>
<td>Alternatives:</td>
<td>New Bridge</td>
<td>No New Bridge</td>
<td>New Bridge</td>
</tr>
<tr>
<td>A</td>
<td>4</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>B</td>
<td>6</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>C</td>
<td>12</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

We begin by plotting the payoff for each alternative on the same graph.

Sensitivity Analysis Example (PS1)

Let’s begin by plotting the payoff for Alternative A. Remember all we need are two points to plot a line.

What is the Payoff for A when the Probability for S1 (New Bridge) is 0. In other words what is the payoff for No New Bridge is built.

What is the Payoff for A when the Probability for S1 (New Bridge) is 1. In other words what is the Payoff if a New Bridge is built.

When we finish, we will have all 3 payoffs on the same graph. Best Payoff is different over the probability range.
Sensitivity Analysis Example (PS1)

Now all we have to do is calculate the intersections using the simultaneous equations:

A (red) and C (green) intersect at .3333.

We can conclude in terms of P(S1):
- A is "best" when 0 ≤ P(S1) < .3333
- C is "best" when .3333 < P(S1) < .6
- B is "best" when .6 < P(S1) ≤ 1

Conclusion in terms of P(S1)

A is "best" when 0 ≤ P(S1) < .3333
C is "best" when .3333 < P(S1) < .6
B is "best" when .6 < P(S1) ≤ 1

Sensitivity Analysis – Conclusion

Why do we not include equal signs for the intersection points?

Now state your conclusion in terms of P(S2):

A is "best" when .6666 ≤ P(S2) < 1
C is "best" when .4 < P(S2) < .6667
B is "best" when 0 < P(S2) ≤ .4

Conclusion in terms of P(S2)
Here, we have the option to choose whether we want to perform the analysis on \( P(S1) \) or \( P(S2) \). In this case, we choose \( P(S1) = P(\text{New Bridge}) \).

Choose the intersecting axes to see the intersection points which are displayed on the table and the graph.

Here, we have chosen the option to view the analysis in terms of \( P(S2) = P(\text{No New Bridge}) \).
Special Notes Regarding Templates

All of the examples shown in class showed payoff tables. Cost tables are handled in a similar manner; however, the templates require costs to be entered as negative numbers. For Sensitivity Analysis, when costs are used, the line at the bottom rather than the line at the top, represents the lowest cost.

Homework

Read and understand all material in the chapter.
Discussion and Review Questions
Recreate and understand all classroom examples
Exercises on chapter web page